

# The Evidence for Massive Star Formation in Early-Type Spiral Galaxies

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**Abstract.** A recent analysis of the IRAS database indicates that the massive star formation rates in early-type (Sa-Sab) spirals are comparable to the massive star formation rates in late-type spirals.  $H\alpha$  imaging of some of the infrared luminous early-type spirals reveals two types of galaxies. One type shows clear signs of interaction, whereas the other type appears to host a nuclear starburst. The occurrence of nuclear starbursts in early-type spirals may be related to the propensity for such galaxies to also host Seyfert nuclei. The evidence for interactions suggests that early-type spirals are evolving in the current epoch.

## INTRODUCTION

Early-type (Sa-Sab) spirals are widely perceived to be the most inert of spiral galaxies. Indeed, the very term "early-type" refers to an early phase of star formation that has long since passed eg. [1]. The perception is based, in large part, on the optical morphology which is dominated by an inert stellar bulge. There are other observational results, however, which suggest that early-type spirals are not as quiescent as once believed. One of the most striking is the fact that early-type spirals are among the most luminous in the population of nearby galaxies ( $D \leq 40\text{Mpc}$ ) when observed in the far-infrared with the Infrared Astronomical Satellite [2]. Adopting the far-infrared luminosity as a measure of the massive star formation rate, one finds that the IRAS data reveals a previously unsuspected population of early-type spirals with star formation rates that rival the most prodigiously star forming Sc galaxies.

## THE HUBBLE TYPE DEPENDENCE OF THE L(FIR)/L(BLUE) RATIO

Data obtained with the Infrared Astronomical Satellite (IRAS) are used to investigate the dependence of the L(FIR)/L(Blue) ratio on Hubble type for a sample of 1462 galaxies selected from the Nearby Galaxy Catalog [3]. Adopting the far infrared luminosity as a measure of the present day massive star formation rate and the blue luminosity as a measure of the past star formation rate, the L(FIR)/L(Blue) luminosity ratio measures the ratio of present to past star formation in a way that is analogous to  $H\alpha$  equivalent widths. Our results (Fig. 1) [2] indicate

- a) The mean L(FIR)/L(Blue) luminosity ratios are similar for Sa's, Sb's, and Sc's.
- b) The range in L(FIR)/L(Blue) luminosity ratios is as large for the early-type spirals as it is for the late type spirals.

Thus, L(FIR)/L(Blue) luminosity ratios do not support what may be one of the most basic tenets of extragalactic astronomy, that the ratio of present to past star formation is correlated with Hubble type.

## $H\alpha$ IMAGING OF LUMINOUS EARLY-TYPE SPIRAL GALAXIES

There is growing evidence to suggest that early-type spiral galaxies are perhaps the most dynamic of all the nearby galaxy systems. The discovery of ripples, shells [4], and counter rotating gas and star disks in some early-type spirals [5] [6] indicate that a major accretion event occurred in the past 1-2 Gyr [7]. We have obtained  $H\alpha$  images for 5 of the most luminous ( $L_{FIR} > 10^{10} L_{\odot}$ ) Sa-Sab galaxies. The  $H\alpha$  images (Fig. 2) suggest two types of early-type spiral galaxies. One type clearly shows signs of disturbance in both the continuum and  $H\alpha$  images. The other type includes galaxies that appear to be undisturbed morphologically, but their entire  $H\alpha$  emission is radiated from a very small,  $\leq 1kpc$ , diameter region centered on the nucleus. The origin of the nuclear  $H\alpha$  emission is unclear, but it is most likely a starburst, an active nucleus or a combination of the two.

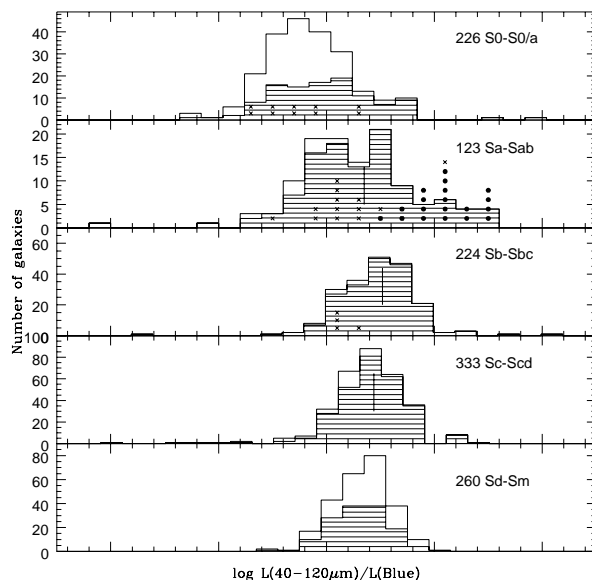
## SUMMARY

The current perception that high mass star formation increases along the Hubble sequence (Sa-Scd) is largely based on measurements of the  $H\alpha$  luminosities and equivalent widths by Kennicutt & Kent [8]. Their measurements do indicate an increase in the ratio of present to past star formation along the sequence Sa to Sc. Our results, however, indicate that both the massive star

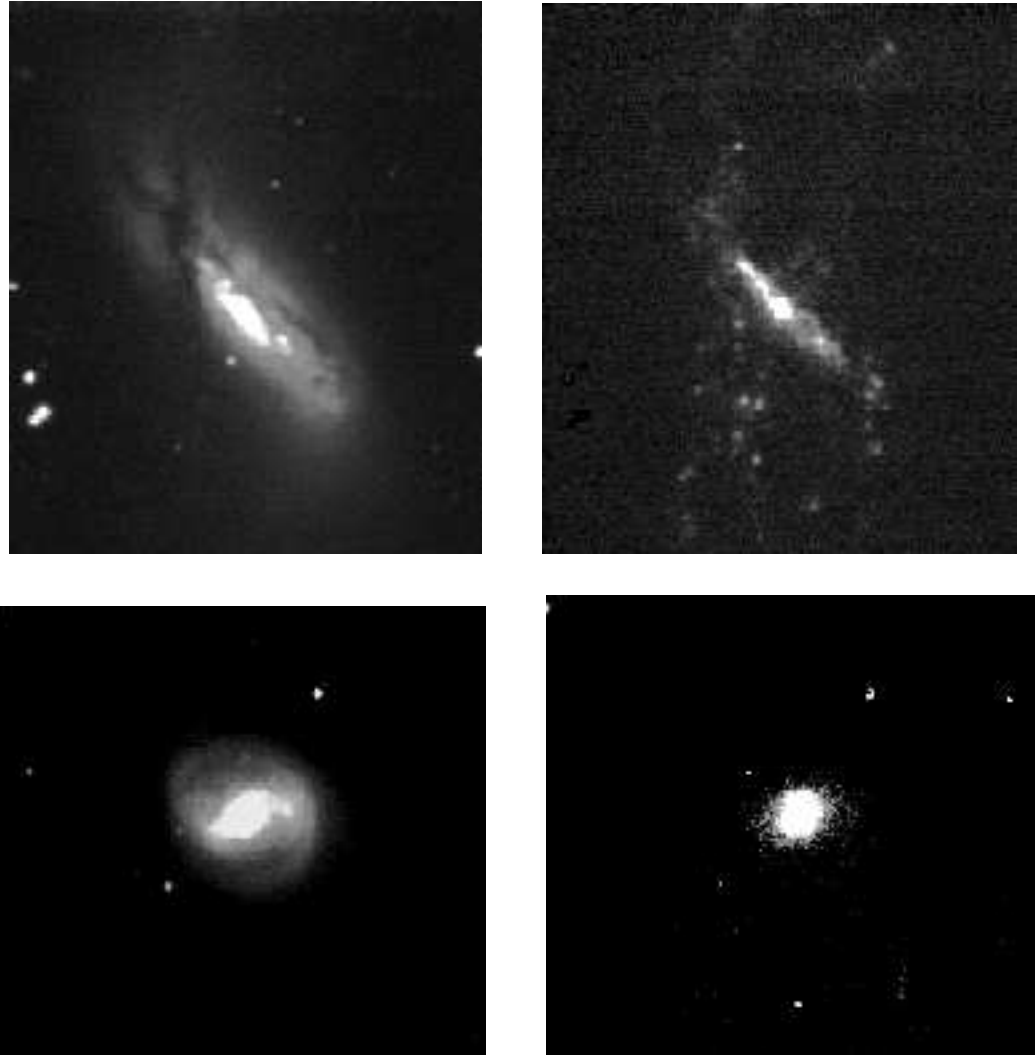
formation rate and the present to past star formation ratio are independent of Hubble type, at least for the Sa's, the Sb's and the Sc's. On the other hand, there is still a lingering controversy over the origin of far infrared luminosity. We are therefore obtaining complimentary  $H\alpha$  images for a complete, all sky, sample of 57, bright,  $m(B) \leq 12$  magnitudes, nearby,  $D \leq 40$  Mpc, early type (Sa-Sab) spiral galaxies in order to better understand the difference between the IRAS results and the existing  $H\alpha$  measurements.

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**FIGURE 1.** Histograms illustrating the Hubble type dependence of  $L_{fir}/L_{blue}$  ratios. The hatched histograms identify FIR detections, the unshaded histograms identify upper limits to the FIR flux. The vertical bar identifies the median of the distribution. Solid circles identify Sa-Sab galaxies with  $L(40-120\mu m) \geq 10^{10} L_{\odot}$ , and crosses identify Sa-Sab galaxies from Kennicutt's sample. Fourteen of Kennicutt's galaxies are classified as either S0-S0/a or Sb-Sbc in the NBG catalog. For details, see [2]



**FIGURE 2.** The continuum (left) and continuum subtracted  $H\alpha$  (right) images of NGC 660 and NGC 1022 illustrate the two types of early-type spirals. NGC 660 shows clear signs of interaction, whereas NGC 1022 appears to host a nuclear starburst.